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GLYPHOSATE – A REVIEW

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In recent years, a large number of herbicides based on the active ingredient glyphosate have been introduced. All claim to be as good, or better, than the original Roundup. The ingredient statements on the label provides little help in differentiating the products since the contents are broken down simply as 'active' and 'inert' or 'other' ingredients. This article will discuss how the contents of the glyphosate products may vary and factors that influence the performance of glyphosate.

Chemical Properties

The active ingredient, glyphosate, is the compound that actually kills weeds. The Roundup Ultra label states that the active ingredient is "Glyphosate, N-(phosphonomethyl)glycine, in the form of its isopropylamine salt". The term 'glyphosate' is the common name of the chemical, whereas 'N-(phosphonomethyl)glycine' is the chemical name that provides information about the actual chemical structure of the herbicide. Regardless of the brand you purchase, the active ingredient for all glyphosate products is exactly the same.

Glyphosate is a substituted amino acid that interferes with amino acid synthesis by inhibiting the EPSPS enzyme. This enzyme is involved in the synthesis of several amino acids, the building blocks of proteins. Several factors contribute to the effectiveness of glyphosate: 1) The EPSPS enzyme is a part of an important metabolic pathway in all plants. Disruption of this pathway is normally fatal to the plant; 2) Glyphosate binds very tightly to the EPSPS enzyme. Thus, once the herbicide reaches the target site, the enzyme essentially is nonfunctional; 3) Plants are inefficient at metabolizing glyphosate, thus the molecule remains intact within the plant until it reaches the target site; and 4) Glyphosate does not cause a rapid disruption of plant tissue. This allows the herbicide to be translocated throughout the plant, providing a more effective kill than herbicides that rapidly disrupt plant tissues.

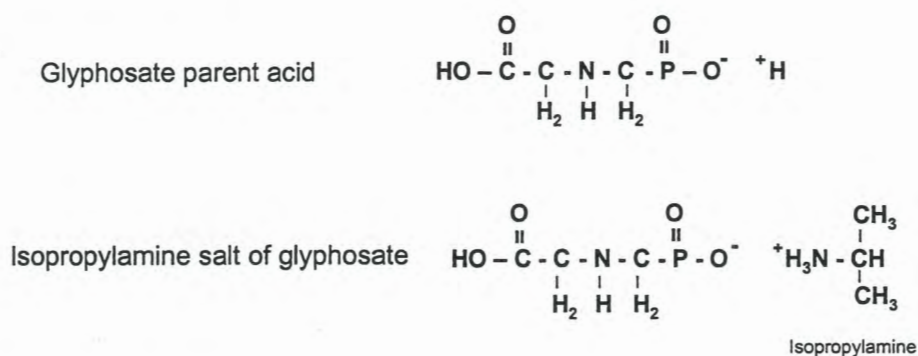
Glyphosate Products

Glyphosate is a type of chemical known as a weak acid. Weak acids can donate a hydrogen ion to other compounds (Figure 1). When glyphosate is formulated into a commercial product, the hydrogen ion on the parent weak acid is replaced with a different salt (ion). The salt itself does not have herbicidal properties, but results in a product that is easier to handle, mixes better with other agricultural chemicals, and/or is more effective than the parent weak acid.

All glyphosate products except Touchdown contain the isopropylamine salt (IPA) of glyphosate. Touchdown IQ contains the diammonium salt (DAM) of glyphosate. The particular salt formulation does not significantly affect the performance of glyphosate. However, some salts may have phytotoxic properties. The trimethylsulfonium salt used in the original Touchdown

formulation caused localized burning of leaves. While this damage was insignificant in comparison to the herbicidal properties of glyphosate, the salt did cause minor injury to the foliage of Roundup Ready crops. The new Touchdown IQ formulation does not have this characteristic.

Figure 1. Relationship between parent acid of glyphosate and the formulated salts found in commercial products.



The label of most glyphosate products reports the concentration (lbs/gal) in terms of both active ingredient (a.i.) and acid equivalent (a.e.). When calculating the quantity of active ingredient in a product, the weight of both the parent acid of glyphosate and the weight of the salt used to formulate the product is considered. The quantity of acid equivalent reported on the label only takes into the amount of parent acid in the product, the weight of the salt formulated with the product is not considered. Thus, acid equivalent is a better measure of the relative strength of glyphosate products since the salt does not contribute to herbicidal activity. When comparing Touchdown to other glyphosate products, it is important to compare acid equivalent rates rather than active ingredient since different salts are used in these products (Table 1).

Table 1. Comparison of glyphosate products.

Product	Salt	Concentration		Equivalent rates of product
		Active Ingredient (a.i.)	Acid Equivalent (a.e.)	
Roundup UltraMax	IPA	5 lbs/gal	3.7 lbs/gal	26 oz
Roundup Ultra, Glyphomax Plus, Glyfos, Glyphosate, etc.	IPA	4 lbs/gal	3 lbs/gal	32 oz
Roundup UltraDry	IPA	71.4%	64.9%	0.75 lbs
Touchdown IQ	DMA	3.6 lbs/gal	3 lbs/gal	32 oz
Touchddown 5	TMS	5 lbs/gal	3.4 lbs/gal	28 oz

The inert ingredients make up approximately 50 to 75% of most glyphosate products. These materials serve a variety of important functions, such as improving the handling characteristics and stability of the product, enhancing compatibility, and most importantly, improving retention and absorption of the herbicide by plants. Any differences in performance of glyphosate products is likely to be caused by the 'inert' ingredients used in the product, rather than the salt of glyphosate used in the formulated product. The specific inert ingredients material used in products are proprietary information, and herbicide manufacturers consider them to be trade secrets.

In terms of herbicidal activity, surfactants are the most important component of the inert ingredients. The types of surfactant formulated with glyphosate have a significant effect on the performance of the specific product. However, manufacturers invest significant resources in developing formulations before the products are introduced to the market. Differences in performance among glyphosate products attributed to the surfactants are relatively small when compared to the other factors that influence field performance. If there were significant differences, it is likely that the herbicide rates recommended on the label would vary to account for these differences. However, all products generally recommend equivalent rates of acid equivalent for similar uses.

Factors Affecting Glyphosate Performance

Consistent performance is one of the primary reasons for the popularity of glyphosate. However, as with any other herbicide, many factors can lead to variable control with glyphosate. This article will review factors that influence the activity of glyphosate and how the herbicide can be managed to minimize fluctuations in performance.

Formulation

The primary difference among the many available glyphosate products is the surfactant mixture found in the formulated product. Surfactants enhance the retention and absorption of glyphosate by plants contacted by the spray solution. Although the blend and amount of surfactants vary among the many glyphosate brands, performance of these products is similar under most conditions. In recent years Iowa State University has conducted numerous experiments to determine if glyphosate products perform differently in the field. Eleven field trials were conducted in 2001 in which the performance of Roundup UltraMax was compared to Touchdown IQ, Glyphos Gold, Glyphomax Plus or other brand of glyphosate. In 91% of the comparisons there were no differences in performance when comparing products at equivalent rates of active equivalent with recommended additives (Table 2). All glyphosate products performed equally on foxtail, velvetleaf and waterhemp in the eleven experiments. Roundup UltraMax provided better control of common lambsquarter than the other formulation in two of nine situations. On other species, the generic formulations performed similarly to Roundup UltraMax in six of eight comparisons, with one situation where the generic performed better and one where it performed worse than the Monsanto brand. These data suggest that performance differences among glyphosate brands are small and should not be a major criteria in product selection.

Table 2. Summary of performance comparisons of different glyphosate formulations applied at equivalent rates in ISU field trials during 2001 growing season¹.

Foxtail		Velvetleaf		Lambsquarter		Waterhemp		Other	
Same	Diff.	Same	Diff.	Same	Diff.	Same	Diff.	Same	Diff.
12	0	10	0	7	2	7	0	6	2

¹Comparisons made between equivalent acid equivalent rates of glyphosate with recommended spray additives for equivalent products.

Spray additives

All brands of glyphosate recommend the addition of AMS under certain conditions (see water quality), but recommendations for surfactants vary widely among glyphosate products. The Roundup UltraMAX label states 'Do not add surfactants, additives containing surfactants, buffering agents or pH adjusting agents to the spray solution when Roundup UltraMAX is the only pesticide used unless otherwise directed'. On the other hand, DowAgrosciences recommends the addition of surfactant with Glyphomax but not with Glyphomax Plus. The differences in recommendations are due to the amount and type of surfactant included in the formulated product. Monsanto believes that Roundup UltraMAX has the optimum blend of additives to maximize performance, and thus there would be no benefit to including additional surfactants in the spray tank. Other manufacturers have chosen to give the user flexibility in selecting additives.

Two questions frequently arise concerning additive use with glyphosate products: 1) Is there a benefit to using additional surfactants with brands that do not recommend them?, and 2) What surfactant is best? The answer to the first question is probably not. Occasionally the performance of glyphosate products not recommending a surfactant might be enhanced by including additional surfactant. However, the inability to predict when this will occur results in the only person benefiting from this practice in the majority of situations is the person selling the surfactant.

Selecting the optimum surfactant is complicated by the fact that manufacturers of surfactants and other spray additives are not required to provide information on the product's active ingredients. Thus it is impossible to compare the numerous products available for this use. The risk of obtaining a poor quality surfactant can be minimized by obtaining products with a high concentration of active ingredients, avoiding products making unrealistic claims, and purchasing spray additives from the seller of the herbicide it is intended to be used with.

Water quality

Whether the water used as the carrier for glyphosate comes from a well or a rural water association, it may contain large amounts of dissolved salts. Water hardness is a measure of how much salt is contained in the water. The harder the water, the higher the salt concentration. Salts dissolved in water may reduce the effectiveness of glyphosate, particularly calcium and magnesium salts. These salts have a positive charge and may associate with the negatively-charged glyphosate molecule, replacing the isopropylamine or diammonium salts found in the formulated glyphosate product. Glyphosate that is bound with calcium or magnesium salts is less readily absorbed by plants than the form of glyphosate present in the product container.

Thus, the presence of calcium and magnesium salts in the carrier can result in a reduction in glyphosate activity.

Although specific recommendations vary, all products containing glyphosate labels recommend the addition of ammonium sulfate (AMS). The role of AMS as an additive with glyphosate is considerably different than the function of the non-ionic surfactants or crop oil concentrates (COC) commonly used with postemergence herbicides. Whereas surfactants and COC's are active primarily on the leaf surface and improve absorption of the herbicide into plants, AMS is primarily active within the spray tank.

The addition of AMS to the spray tank reduces the amount of glyphosate inactivated by antagonistic salts present in the water. The rate of AMS required to achieve this benefit is dependant upon the hardness of the water, and can be determined by water testing. Most applicators in Iowa choose to estimate how much AMS is needed, rather than having their water source tested for hardness. Few water sources in Iowa have sufficient hardness to require the maximum rate of 17 lb AMS per 100 gal water of AMS recommended on most glyphosate labels; in the absence of testing, 8.5 lbs per 100 gal of water should be adequate to counteract the antagonistic effects of most water sources in Iowa.

In addition to negating the effects of hard water, AMS may enhance glyphosate performance on velvetleaf regardless of water quality. The leaf surface of velvetleaf has relatively high concentrations of calcium salts. This calcium on the leaf surface may antagonize glyphosate in the same manner as the salts in hard water. AMS reduces the formation of calcium-glyphosate complexes on velvetleaf leaves and therefore improves performance.

Spray volume

The Roundup UltraMax label recommends the use of 3 to 30 gallons of water per acre, whereas the Touchdown IQ label suggests a volume of 3 to 40 gallons. Research has documented increased performance of glyphosate when applied in water volumes below 10 GPA compared to 20 GPA or higher. There are two primary factors responsible for this response. First, as spray gallonage increases, the quantity of antagonistic salts increases. Thus, the potential for calcium or magnesium salts to inactivate glyphosate increases as spray volume increases.

The second factor that may cause reduced glyphosate performance at high spray volumes is a simple dilution effect. As spray volume increases, the ratio of formulated glyphosate to water decreases (one quart of Roundup in 10 gallons water = 1:40; one quart of Roundup in 20 gallons = 1:80). The ratio of active ingredient to water is probably of little significance, but as spray volume increases the amount of surfactant per gallon of water also decreases. The decrease in surfactant concentration that occurs as spray volume increases may negatively impact product performance under certain situations.

Although the effect of spray volume on glyphosate activity is well documented, other factors need to be considered when determining the optimum spray gallonage to use. Two potential problems with low spray volumes are increased risk of drift and less effective penetration and coverage of dense plant canopies. Relatively small spray droplets are required to achieve uniform coverage at spray volumes less than 10 GPA. While small droplets can increase

glyphosate activity, they may increase the likelihood of spray drift. The second limitation to low spray volumes is that spray coverage of the target may be diminished. As spray volume is reduced there is an increased variability in deposition of spray droplets and thus a greater likelihood that individual weeds may not intercept a lethal dose of the herbicide. The variability in spray deposition increases as the density of the plant canopy increases.

Several factors should be considered when selecting a spray volume to use with glyphosate, including effects on herbicide activity, target coverage and drift potential. For most agronomic situations, 10 to 15 gallons per acre has been shown to minimize deleterious effects on performance while allowing effective coverage of weeds present in corn and soybeans. Higher volumes (20 GPA) may be beneficial in situations with dense weed infestations, well-developed crop canopies, or large weeds.

Environment

Plants respond continuously to the environment to protect themselves from stressful conditions (drought, heat, cold, etc.). For example, during dry or hot weather plants conserve water through changes in both the composition and thickness of the cuticle on the leaf surface. Although poorly understood, plant responses to the environment significantly affect plant tolerance to herbicides. Most herbicide labels contain vague statements regarding environmental influences on herbicide performance. The Touchdown IQ label states: 'Touchdown requires actively growing green plant tissue to function'. Most growing seasons contain short periods of time when extremes in temperature or moisture essentially cease active plant growth, herbicide applications made during these periods may provide ineffective control.

Managing environmental-induced fluctuations in herbicide efficacy is one of the most difficult challenges of persons involved in weed control. Attempts to develop tools to aid farmers or custom applicators in determining the optimum herbicide rate or spray additive based on prevailing weather conditions have been hindered by the complex interactions between plants and the environment. In one study, researchers searched for the key environmental factors that affected postemergence herbicide performance in 60 research trials. The effectiveness of the herbicide was strongly affected by minimum temperatures in the seven days prior to application, soil moisture deficits during the ten days prior to application, and the maximum temperature on the day of application. The task of adjusting application parameters in response to the environment is further complicated by the fact that each weed species responds differently to the environment. Thus, a single decision guide for adjusting spray parameters in response to weather would have limited applicability because of the mixed weed infestations found in most fields.




Our limited understanding of how weeds adapt to environmental fluctuations restricts how we can use weather information to optimize glyphosate applications. However, the likelihood of performance failures can be reduced by monitoring weather conditions and adjusting application parameters accordingly. While we are unable to predict the precise herbicide rate needed under specific conditions, we can predict when weeds are less susceptible to control. Under these conditions, herbicides rates should be increased or applications delayed until more favorable conditions occur.

Time of day

Soon after the introduction of Roundup Ready soybeans, control problems with glyphosate applications made in the evening were observed. Subsequent research confirmed that the activity of glyphosate can decline with applications made early in the morning or in the evening. In certain weed species, this response is at least partially due to diurnal leaf movements. Leaves of velvetleaf and many other plants hang vertically after the sun has set, and then raise parallel to the soil surface during the day in order to intercept sunlight efficiently. Changes in leaf orientation can influence how much herbicide spray is intercepted by a weed.

Researchers in Arkansas evaluated the influence of time of glyphosate application on several weed species (Table 3). Both hemp sesbania and sicklepod expressed diurnal leaf movements, with leaves oriented approximately 10 degrees from horizontal during the day and at 80 degrees during the night and early morning. Approximately 70% less herbicide was intercepted by the weeds when applications were made at night than during the day due to the change in leaf orientation. Control of hemp sesbania was closely correlated with leaf orientation, with control below 50% when applications were made during in the morning or evening, compared to 80% control when applied at 11 AM. Although sicklepod control varied with time of application, Roundup performance was not as closely correlated with leaf orientation as seen on hemp sesbania.

Table 3. Influence of time of day and leaf orientation on performance of 1 qt/A Roundup Ultra.

Time of Day	Leaf orientation	Weed Species	
		Hemp Sesbania	Sicklepod
		% Control	
6 AM		40	100
11 AM		80	92
9 PM		22	50

Adapted from Norsworthy et al. 1999. Weed Technol. 13:466-470.

The research indicated that a decrease in spray interception due to leaf orientation may be responsible for performance problems when Roundup was applied late in the day or early in the morning. However, the research also shows that other factors were involved in this response. Many physiological processes in plants are influenced by light, and it is possible that changes in plant metabolic activity between the dark and light also influence herbicide activity. Other research reported that the amount of glyphosate required to reduce the activity of the target site enzyme (EPSPS) was more than two times greater in the dark than in the light (Tokhver,-A.K.;

Pal'm,-E.V. Light-dependence of the inhibiting action of glyphosate on the shikimate pathway in cotyledon leaves of buckwheat seedlings. *Sov-Plant-Physiol.* 33: 748-753.).

Problems with reduced control when glyphosate is applied in the evening or morning are most likely to occur with species that have a relatively high level of tolerance to the herbicide. In some cases the influence of time may be overcome by increasing the rate of herbicide; however, there are no concrete guidelines to determine when and how much to increase rates to overcome this affect.

Dew

A wide range of views on the influence of dew on herbicide performance exists among farmers. Some state that they see the best herbicide performance when a light dew covers the foliage of weeds, whereas others believe the presence of dew greatly reduces weed control. A recent study investigated the interaction between dew and spray volume on glyphosate performance (Table 4). Glyphosate activity was not affected by dew when applied at the lower spray volumes (16 and 32 GPA). However, control was reduced with 100% dew coverage on the foliage when glyphosate was applied in 48 GPA. In addition, glyphosate activity was reduced at 48 GPA compared to the lower spray volumes at all dew levels. The researchers speculated that the diminished glyphosate activity at high spray volume and 100% dew was caused by spray runoff from the saturated leaf surface. They concluded that moderate levels of dew would have minimal impact on glyphosate when applied at typical spray volumes.

Table 4. Influence of dew and spray volume on glyphosate performance. (Kogan and Zuniga. 2001. *Weed Technol.* 15:590-593).

Spray Volume	Dew Level		
	0 %	50%	100%
	% control		
16 GPA	88	89	89
32 GPA	82	88	88
48GPA	65	65	59

Summary

As with any herbicide, the performance of glyphosate is affected by many factors, several which the applicator has little or no control over. Performance variability due to differences in the formulation of the many available glyphosate brands is relatively small compared to that caused by environmental and application parameters. The potential for control failures varies widely among weed species based on their inherent sensitivity to glyphosate. Control of giant foxtail with glyphosate is less likely to be affected by environmental conditions or application parameters than velvetleaf simply because giant foxtail is much more sensitive to glyphosate than velvetleaf. Plant stress caused by environmental conditions probably is the primary source of control failures with glyphosate. Keep in mind that any condition that reduces the growth rate of plants probably will reduce the activity of glyphosate. Under these conditions, consider all factors that influence herbicide activity in order to minimize the risk of control failures.